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ABSTRACT

The two articles dealing with problem solving and technology in this publication should be useful to those developing the kinds of materials, experiences, and thinking that elementary school industrial arts offers children. The first article accepts problem solving as an educational goal and reports a timely and universally acceptable approach. Earle Lomon, Bette Beck, and Carolyn Arbetter present the need for problem solving abilities at all levels of the population and demand integrative and flexible cognitive skills. They provide examples of how problem solving can be arrived at through the Unified Science and Mathematics for Elementary Schools program, which helps children develop real problem-solving abilities. In the second article Robert M. W. Travers compares the long developments in the early technologies of metals with the development of education. He suggests that a technology can be developed by borrowing from other fields (such as operant conditioning efforts) or through unique development based upon sound scientific knowledge (such as educating man as an information retrieval system in light of computer technology). (YLB)

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PROBLEM SOLVING AND TECHNOLOGY

ARTICLE 1

Earle L. Lomon, Betty Beck, Carolyn C. Arbetter
"Real Problem Solving in USMES:"
Interdisciplinary Education and Much More
School Science and Mathematics, LXXIV, (October 1974)
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ARTICLE 2

Robert M. W. Travers
"Directions for the Development of an Educational Technology"
in Paul W. F. Will, Editor, **Technology and the Curriculum**
(New York: Teachers College Press, 1968)
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FROM THE PRESIDENT

The American Council for Elementary School Industrial Arts, a council of the American Industrial Arts Association, was established in 1963 by forty-nine individuals who felt that industrial arts experiences should be provided as a part of the elementary school experiences of all children. Membership in the council has grown over the years and so have the services which are provided by the council to the membership. We hope that those who have been affiliated with us have also grown. This publication is designed to continue this professional growth in an effort that we may make good educational experiences even better educational experiences for our elementary children.

The purposes of the council are to:

. . . clarify, promote and improve industrial arts and career education as a vital part of the elementary school curriculum.

. . . coordinate, on a national level, the efforts of all who contribute to the development of elementary school industrial arts and career education.

. . . publish materials relating to trends and issues in education for young children which will be of informational and practical use to the membership of the council.

. . . organize action which will facilitate the general purposes of ACESIA, including the receiving, holding and administration of funds and property.

For those who wish to become affiliated with the elementary council, information may be obtained by writing to:

ACESIA Membership Chairman
American Industrial Arts Association
1201 Sixteenth Street, N.W.
Washington, D.C. 20036

PREFACE

This publication marks the second of a series of small monographs which are being prepared by the publications committee for distribution to the membership of the American Council for Elementary School Industrial Arts.

Special recognition for the articles selected for this publication is also due Wes Perusek of the New Jersey State Department of Education who served as chairman of the publications committee during the time when these articles were selected. Credit is also due to the following members of the publications committee: Clarence Calder from the University of Connecticut, Luvern Eickhoff of the University of North Dakota, Laddie Gribick of the New Jersey State Department of Education, and Mary-Margaret Scobey of Eugene, Oregon. Gratitude is also expressed to the authors and publishers for allowing the council to reproduce the articles in this monograph.

The two articles presented in this publication are thought to be especially useful to anyone working with children. They should be very useful to those developing the kinds of materials, experiences and thinking which elementary school industrial arts offers children.

Developing thinking skills involves problem situations and problem solving as critical features. Problem Solving often remains when any statement or list of education outcomes or goals has been reduced to its core. The first article accepts this as a goal and reports a timely and universally applicable approach. Earle Lomon, Bette Beck, and Carolyn Arbetter present the need for problem solving abilities at all levels of the population. These abilities would be aimed at any ". . . practical, immediate impediment to good, safe or pleasurable living." And, they call for integrative and flexible cognitive skills. The Unified Science and Mathematics for Elementary Schools (USMES) program has been established to help children develop real problem solving abilities and the authors provide examples of how problem solving can be arrived at through the USMES approach.

In the second article, Robert M. W. Travers compares the long developments in the early technologies of metals with the development of education. He suggests that a technology can be developed by borrowing from other fields or through unique development based upon sound scientific knowledge. The former is apparent in operant conditioning efforts while the latter has only begun to be developed in educational circles. In presenting the properties of the physical and social environment which support intellectual development, Travers offers critical observations for teachers, curriculum writers and program developers.

It is hoped that the obvious emphasis which these authors bring to the potential contributions of elementary school industrial arts are evident to the reader.

Real Problem Solving in USMES:
Interdisciplinary Education and Much More

Earle L. Lomon, *USMES Project Director*
Betty Beck, *Associate Director for Development*
Carolyn C. Arbetter, *Associate Editor*

The Need

The persistence and growth of Man as a species were due to his capability as a problem solver in an intricate and hostile environment. It appeared for a short period of recent history that the major problems of survival had been licked; that maintenance of this modern society and increased opportunities for leisure and pleasure were the most important concerns. This was reflected in education which turned more and more towards structured studies of disciplines and special vocations, an excellent preparation for a world which subsisted on high technology, but in which the organizational principles were understood and in which life was to present us with no completely unexpected challenges.

It was not to remain so for long! The very success of the human species has led to growth in population, a depletion of resources, an intricacy within the society, and a rapidity of change which confronts our minds with many difficult dilemmas. Finding our way out of these dilemmas demands a very high degree of flexible, sophisticated real problem solving ability at all levels of population. Having a few expert problem solvers at the helm will not do. It is in the nature of our individualistic, yet highly interdependent, society that the health of the society depends on the responsiveness (and responsibility) of many people; the individual cannot leave his happiness in other people's hands. Thus, most of us must become good solvers of real problems.

Yet trends in education over the past century have mitigated against a flexible, broad preparation of individuals. There has been a sharply decreasing amount of exposure to whole situations, with all the complexity of reality, in favor of specialist studies where the goal is defined by the discipline and the challenge to the intellect consists in scaling a peak, while ignoring the surroundings. It is urgent that Real Problem Solving become an effective and integral part of education at all levels. For this and other reasons the 1967 Cambridge Conference on the Correlation of Mathematics and Sciences in the Schools[1] recommended the development of a curriculum for elementary schools in which the subject areas would be integrated through the work by students on real and practical problems. The Unified Science and Mathematics for Elementary Schools (USMES) program, funded since 1970 by N.S.F., was a direct outgrowth of those recommendations.

What is a "Real Problem?"

There are a variety of uses of the phrase "real problem" which are not relevant to the need for practical problem-solving skills. Sometimes "real

1. *Goals for the Correlation of Elementary Science and Mathematics*, The Report of the Cambridge Conference on the Correlation of Science and Mathematics in the Schools, Houghton Mifflin, Boston, Mass. 1969.

problem" is used to denote a fragment of the whole situation at hand with boundaries carefully drawn and controlled. Often it means a made-up problem which however is consistent with physical law and the general societal structure. An "application" of a mathematics formula or a science concept is an attempt to relate such abstracts to reality, but it eliminates the need to search for the knowledge and methods that may apply.

Problems which are real in the above ways may have many educational uses, but they will not prepare a person to cope with the complicated and many-faceted problem situations met in real life. In this article, as in USMES, a "real problem" connotes a practical, immediate impediment to good, safe, or pleasurable living. Is the cafeteria service lengthy, crowded, or wasteful? Is the classroom a good place to learn? Do people have difficulty crossing the street near the school? What are the best products to buy with our budget? Such problems challenge children and have a range of attributes met only in problems that are real in this sense.

Such a problem is not easily defined so that it leads to clear-cut avenues of investigation which will help in arriving at a practical solution. The variables importantly influencing the problem are many and difficult to discern. They are also not easily quantified. Dealing with the problem involves observations, modelling, discussion, value judgments, decision-making, and communicating—hence, the whole range of skills and subject areas. The process is long-term and must go through many phases of action and stages of partial solution. Even the goal of the "solution" is not obvious, but a set of values must be brought forth and debated.

A real problem is then ill-defined, complex, and many-faceted. Tackling such a problem successfully requires more than the ability to handle the range of specific things that will need to be done. The more important task is to make sense out of the vagueness, relate the many facets, and pull together the strategies which will ameliorate the situation. Thus, the cognitive skills needed are flexible and integrative, not specific and hierarchical. This distinguishes them from the cognitive skills developed by most of present-day education. Learning the "cognitive strategy" required for Real Problem Solving is different from learning other kinds of strategies. Gagne has done research in this area and we quote his findings:

> Let me turn now to still another kind of learning outcome which everyone agrees is of great importance—cognitive strategies. How does the student learn the internal controls which make him an efficient learner, and efficient "rememberer," an ingenious problem-solver?
>
> Several points should be made at the outset. First, such strategies are probably not learned quickly, or in an all-or-none manner, as intellectual skills seem to be. Instead, they probably undergo continued refinement and sharpening as the individual acquires greater experience. One does not "teach the student to think" by means of a single course in thinking. Instead, if he is properly challenged, he continues to become a better thinker all his life long, or at least until senility takes its toll.
>
> . . . if a teacher wants a student to become a good thinker in the field of science, he must provide many opportunities, throughout the course of his instruction, for him to encounter, formulate, and solve problems of many varieties. . . .[2]

By contrast, Gagne describes intellectual skills in this way:

> These are relatively specific intellectual operations by means of which the individual relates to his environment. . . .
>
> Some of my previous writings have been concerned with methods of finding out what structure of prerequisite intellectual skills are like and how they may be predicted. These structures are called learning hierarchies.[3]

2. R. M Gagne, "Instruction Based on Research in Learning," *Engineering Education*, vol. 61, no. 6, March 1971, p. 552.

3. Ibid., p. 521.

It is the prime purpose of the USMES curriculum to provide the repeated, comprehensive exposure to real problem solving situations that develop Gagne' "cognitive strategies."

Real Problem Solving—How It Works in an USMES Class

Most textbooks and curriculum projects include problem solving in some form in their materials. The problems included are usually short-range, however, and are used to show some practical use for a specific skill already "taught" in the abstract. Students know that to "solve" these problems means to find the correct answer, following procedures indicated in the previous chapter of their book.

Real Problem Solving is different. An USMES unit presents students with a challenge which states a real and practical problem. The problem is real in that it applies to some aspect of school, home, or community life; it is practical in that the children's work may lead to some improvement in the situation being investigated which would not have come about without their efforts. In responding to the challenge, students become involved in all aspects of good problem solving: observation, collection of data, representation, and analysis of data, formulation and trial of successive hypotheses, and the decision on a final action to be taken.

The practicality of the problem not only motivates the students, but also provides a criterion (try it and see if it works) for judging the correctness of hypotheses and conclusions. Many teachers have found that this concept helps them to react in a positive way to every idea and to promote various approaches to the problem.

In USMES units long-range investigations are initiated and carried out by students in response to the challenge; most classes spend 45 to 60 sessions on the problem before a "good" solution has been found and implemented. The challenge itself focuses the open and free activities suggested by the students. Hence, in addition to the free choice inherent in the open classroom situation, the real problem approach enables the students to discern a purpose to their work and to achieve depth in their investigations.

The level of sophistication of these investigations as well as the consequent solution varies with the age and ability of the students. If the problem is real to students at a certain level of understanding, their solution at the same level will also have meaning. Finding solutions to real problems at any level requires the collection of real data. This eliminates the often-used simplified approach to problem solving which uses artificial data, consequently limiting the skills that can be learned. At any age, student work with real data leads to an optimal development of skills. The goal of bringing about some change is inspiring to the extent that students overcome many difficulties and frustrations in their efforts and accomplish things far beyond previous expectations.

In summary, real problem solving develops the problem-solving ability of students and does it in a way that leads to a full (learning-by-doing) understanding of the process, as well as to a maximum acquisition of skills and concepts. Moreover, it is motivation to the student to learn more in order to apply it toward solving the problems around him.

Interdisciplinary Education Through Real Problem Solving

There are many modes and levels of interdisciplinary learning extant today. Combining the subjects of algebra and geometry within mathematics, which most people would consider a single discipline, is still an issue in American education. Unified science programs bring together all the natural science sub-disciplines through projects. Math curricula reach

out to natural science, social science and engineering topics for applications; science courses include required mathematics instruction in the relevant context. Teachers or teacher teams often arrange their instruction to look at a given system or problem from the separate standpoint of various disciplines—sometimes called a multidisciplinary approach.

A Real Problem Solving curriculum has several advantages with respect to interdisciplinary education:

i) It is natural to use many disciplines in solving a real problem; there is no need to impose a multidisciplinary structure.

ii) The number and range of disciplines are unrestricted. Few real problems find solutions within the bounds of one or two disciplines. Skills, concepts, and processes from many disciplines will be called on. In addition, a balance of the cognitive, psychomotor and affective aspects of the disciplines is inherent in such activities.

iii) The importance of the disciplines is demonstrated. The students become aware of their role in many different situations.

iv) The relationship among disciplines and how they depend on each other is brought out.

v) Concrete examples establish a solid base for the conceptual schemes of each discipline.

vi) Educators are now becoming sharply aware that disciplines change their boundary lines and that new disciplines are emerging. Real Problem Solving avoids the conventional definition of disciplinary boundaries and immerses the student in those areas of relevance which may become the disciplines of tomorrow, such as environmental engineering.

The Impact of Real Problem Solving in the Total School Program.

The unique aspect of USMES is the degree to which it provides experience in the real problem solving process. That is its major goal and one of the items being examined in the evaluation program which is discussed below. Many would agree that this aspect of learning is so important as to deserve a regular place in the school program even if it means decreasing to some extent the time spent in other important areas.

Fortunately, real problem solving is also an effective way of learning many of the skills and concepts in a whole range of school subjects. Evidence to date indicates that substantial time can be spent on USMES with no loss in the rate of learning the standard school subjects. Thus, skill and concept learning can be maintained at the same level, while being made more effective through application in problem solving. While the testing of basic skills supports the general finding, documentation of students' work provided the details on what is learned in the various challenge activities. Information gained from monitoring many classes is included in chart form under broad categories in the USMES Guide and in more detail in the unit resource books. A much more thorough study of the mathematics content of student responses to four USMES challenges has been conducted by a Michigan State University graduate student.[4]

The interdisciplinary nature of Real Problem Solving offers a tremendous opportunity to enrich the spectrum of learning without diminishing any aspect. However, research and planning are needed to make good use of this opportunity.USMES, or a similar program, can enrich each subject area and therefore can be allotted time normally given to each part of the school program. On the other hand, it will not fulfill every cognitive and affective need; learning is best attainted through a mixture of modes and strategies. Furthermore, the openness of USMES activities implies that

4. *The Mathematical Behaviors Derivable From the Program of Unified Science and Mathematics for Elementary Schools*, Thesis for the Degree of Ph.D., Michigan State University, Sompop, Kairojananan, 1973.

other more structured programs may be needed to fill in gaps, or to teach the more formal aspects of the disciplines which are within the cognitive range of children in grades 1-8.

Thus, it is not the relatively simple matter of taking out an old curriculum in one or more subject areas and replacing it with USMES. Rather, there is a need to think the whole program, deciding how to combine USMES with other curricula to enhance the effectiveness of all components. The USMES project is studying this aspect through monitoring the ways in which teachers and districts have been dealing with the situation. The articulation of USMES units with other materials is noted to some extent in the unit resource books. A much more extensive study is being undertaken now and will be the basis for a separate volume. This is a large enterprise which will require the help of those familiar with various curricula, with learning theory, and with classroom practice. The payoff can, however, be very large; instead of merely improving pieces of the curriculum, there is the opportunity to fundamentally alter and improve the educational system. We hope that many readers of this article, and others, will use their expertise to help in such a redesign of the learning program.

Evaluation of Real Problem Solving

The USMES project staff and an evaluation staff at Boston University School of Education are engaged in a wide range of data-gathering activities in order to better evaluate the success of different aspects of the program and to provide schools and districts with information to use in making adoption and program decisions.

Student activities in response to the unit challenges are monitored in all the classes involved in the development of first-trial implementation phase of the program and in a sample of the classes involved in the other implementation programs. This monitoring takes the form of detailed reports from teachers and trained local observers who visit the classes regularly. In-depth interviews are also conducted with teachers, principals, district administrative personnel, and resource team leaders. The data gathered in these ways is used in developing and refining the unit challenges and materials and the teacher-training and implementation strategies.

In addition, specific instruments, designed by Professors Bernard Shapiro and Mary Shann of Boston University in collaboration with others, are administered to a sample of the classes using USMES and to non-USMES control classes (matched for grade level and school). The instruments include a situational problem-solving exercise and a classroom activity and interaction scale. The reading comprehension and mathematics computation subtests of the Stanford Achievement Test are also administered. The data gathered using these three instruments provides information on whether the USMES approach is successful in teaching real-problem solving, whether USMES produces a different kind of classroom atmosphere in terms of activities and interactions, and whether USMES has an effect on students' basic reading and math skills.

Two situational problem-solving tests have been developed to date and a third is currently being worked on. In each of them, children are presented with a real-problem situation and asked to spend up to an hour working toward its solution. The children's behavior, verbal and non-verbal, during that time is documented. During the 1971-72 school year the Notebook

Problem Test was administered and the results were very gratifying. Children were asked to examine three different spiral-bound notebooks (that differed in dimension, number of pages, quality of paper, number of lines per page, price, and so on) and recommend which should be ordered in quantity for student use. Normal classroom tools such as pencils, pens, rulers, and erasers were made available to the children to use during their investigation. In the pre-test there were no discernable differences between the USMES and the control classes on the two dimensions analyzed: (a) whether or not the reason given was based on dimensions that were measurable within the test situation, and (b) the highest level of proof associated with the reasons given. In the post-test, however, every USMES class altered its scores to reflect predominantly quantifiable reasons for choice and higher levels of proof involving suggested or performed measurements.

During 1972-73 the Playground Design Problem was used. Groups of five children were asked to design a playground for an open piece of land near the school. They were supplied with basic measuring instruments, a catalogue of playground equipment, and hypothetical allotment of money to spend. Due to problems with the data collection process, the trends (which were in favor of the USMES class) were judged to be not significant. Efforts are underway to correct these problems so that the 1974-75 data can be compared with the results of the Notebook Problem and with teacher interview data that indicates that, almost without exception, teachers feel that USMES teaches problem-solving skills.

Results from the activity and interaction scales used in 1972-73 showed that students in USMES classes are more likely to be involved in small group work, to contribute ideas during class discussions, and to interact with their peers about the work at hand.

The preliminary results from the analysis of the Stanford reading and mathematics subtests administered during the 1972-73 school year showed no significant difference between the USMES and the control classes. The importance of this finding was that it showed that children using USMES do not lose anything in basic skills. These results are not inclusive,however, due to the small sample size. Results from the 1973-74 data were more favorable toward USMES. After adjustments were made for pre-test differences, the analysis revealed that overall the USMES classes attained significantly higher scores in both the reading and mathematics post-tests. The 1974-75 evaluation program takes a much more intensive and extensive look at the effect of USMES on student performance and attitudes for these and other disciplines.

Activities, Skills and Concepts in Pedestrian Crossing Unit: An Example

In conclusion, the following paragraphs describe the activities which have occurred and the related interdisciplinary skills and concepts which have been covered in several classes in response to the challenge in the Pedestrian Crossing unit: Recommend and try to have a change made which would improve the safety and convenience of a pedestrian crossing near your school. The students were introduced to the challenge in either a direct way by being asked whether they had trouble crossing any streets coming to school, or in the context of a discussion about traffic around the school and the problems they had in getting to school. Student response in the different classes varied according to the specific problem involved. One 4th grade class in Lansing, Michigan was concerned about the crossing

directly in front of the school; a 5th grade class in Lexington, Massachusetts felt the rotary near the school presented a dangerous situation; 5th grade students in Washington, D. C. investigated whether it was safer to cross a street at a controlled intersection or at an uncontrolled section; 2nd grade students in Watertown, Massachusetts set out to find out whether one street was as hard to cross as a classmate said it was.

For the sake of the readers, the following sections present the activities in order to approximate time when initiated. This, however, does not mean that the activities occurred in that or any other such precise order. In an USMES class students determine the flow of the investigation and many reruns are necessary as students find, by trial and error, better procedures to follow.

Not all classes become engaged in all of the activities listed; however, a large proportion are included in some way as students become deeply involved in being able to make some change in the situation. Younger children are not as sophisticated in their investigations as older students. They may not become involved in selecting samples; they may draw only bar graphs of their data; and they may use graphical means of finding ratios rather than computing them.

Omitted from the paragraphs because they arise within all activities, are the interpersonal skills learned by the students as they communicate with each other and make decisions as they work together in small groups on a task and critique each others' work.

SKILLS, CONCEPTS *(S—Science, M—Math, SS—Social Science, LA—Language Arts)*	*TYPE OF ACTIVITY* *Introduction and Discussion of Challenge*
Problem Definition (S, M, SS)	In the initial discussion of the challenge, students first identify some possible aspects of the problem. (Some classes repeat this brainstorming session after an observation of the problem area.) For example, in one class, three factors which made safe crossing difficult were listed as: 1) the speed of the cars, 2) the number of cars, and 3) the time of day.
Communications (LA)	
Organization and categorization of ideas (S, M, SS, LA)	
	Determining Possible Investigation and Setting Up Priorities for Group Tasks
Assignment of relative importance and priorities to tasks (S, SS)	In many classes the students decide that they need to measure the crossing times of students, to count the number of cars passing through the intersection, to determine the time students have to cross between cars, and to find the speed of the cars. As the various tasks are outlined, students decide which tasks should be tackled first and set up small groups, if possible, to carry out the investigations.
Redefinition and reordering as new tasks are identified (S, SS)	As a class progresses in its first investigations of aspects of the problem, students see the need for other information.

For example, in many classes, the need for a scale model of the crossing area arises as students talk about the problem in the classroom and realize that they will eventually have to present their ideas to some person or group in a position of authority. The process of making a scale model involves several measurement and construction tasks not previously envisioned. Students regroup as a start is made on new tasks and earlier tasks are completed.

Approximation and measurement (M, S)

Use of measuring instruments (S, M)

Design and refinement of procedures (S, SS)

Determination of sampling requirements (M, SS)

Comparison of accuracy of instruments (M, S)

Counting and Ordering (M)

Addition, subtraction, multiplication, division (M)

Fraction, ratios, percents (M)

Data Collection

In many classes during the course of unit work, data is collected as follows:

1) Measurement of time (using stopwatch): crossing times of students; arrival times of cars at intersection; time to travel certain distance; times of red, green, and walk sequences of traffic lights, etc.

2) Measurement of distance (using variety of instruments): lengths and widths of streets, heights of buildings and trees; placement of signs; sight distance along street; braking distance; viewing distance of motorists; height of children, etc.

3) Opinion surveys of students and adults about safety of crossing, possible improvements, etc.

Graphing (M, S, SS)

Statistics (M, S, SS)

Geometry (M, S)

Drawing Inferences (S, SS)

Data Representation and Analysis

As students put their collected data in a form that can be readily analyzed and explained to others, they make computations and construct graphs as follows:

1) Finding gap times between cars.

2) Computing speed of cars.

3) Finding median (and average) crossing times, waiting times, gap times between speeds of cars, measurements of various distances.

4) Compiling data from opinion survey; comparing results from different size samples; computing percentages, ranges.

5) Conversion of measurements for scale models by computation or construction of conversion graphs.

6) Construction of bar graphs of individual crossing times, width of streets, etc.

7) Construction of histograms (and cumulative frequency graphs) of crossing times, gap times, speeds of cars.

8) Comparing data of crossing times and gap times between cars; number and speed of cars and time of day, etc.

Construction

Approximation and Measurement (M, S)

Computation and Geometry (M)

Use of tools, materials (S)

Electricity (S)

In many classes students construct trundlewheels, scale models of problem areas, scale models of cars and people, model traffic lights and signs.

Action Resulting from Investigations

Letter and Report Writing (LA)

Political Science (SS)

Economics (M, SS)

Film Production (LA, S)

As students come to some conclusions about improvements that may be made, they try to exert influence so that the changes are made. In many cases they are successful; in all cases they learn a great deal from the effort. Letters and reports are sent to authorities, interviews conducted and safety films made. The second grade class was successful in having the location of a crosswalk changed; the fourth grade class found that traffic engineers had come to the same conclusion about the need for an overhead crosswalk; a fifth grade class convinced the police that the traffic policeman should be stationed at a crossing where there was no control, rather than at the controlled crossing. Another fifth grade class tried out a "Please Use Your Turn Signal" sign. The last class then used their data, showing an increase from 25% to 96% in the number of people using their turn signal, to try to convince authorities to put up such a sign.

The authors wish to express their appreciation to the many individuals who have contributed to the development and refinement of these ideas over the past few years.

Directions for the Development of an Educational Technology

Robert M. W. Travers

Robert M. W. Travers is Distinguished University Professor at the Western Michigan University at Kalamazoo

Technologies have developed under many different circumstances. Sometimes they have been born as children of scientific knowledge, but in earlier times they emerged as man made a series of practical discoveries in which luck played a prominent part. According to History of Technology, edited by Singer and his associates, one of the earliest complex technologies to be developed was that related to the utilization of copper.[1] Native copper was in use before the discovery of smelting; but pure copper ingots are rare, and any extensive use of the metal had to be preceded by the development of means of reducing an ore to the metallic form. A thousand years probably elapsed between the first use of native copper and the first crude smelting process, and one can hardly be surprised that the development took so long. In the absence of any scientific knowledge, the discovery of smelting was dependent upon the presence in a region of both a suitable ore and combustible materials. The first production of copper from an ore probably occurred when somebody tossed a chunk of cuprite or azurite into a hot fire and found next day that it had turned into a copper-like mass. Perhaps this had to happen hundreds of time before anybody even noticed the nature of the product when the embers died down or connected the copper found with the brightly colored stone that had been thrown into the fire on the previous evening. A lesson that takes a thousand years is clearly one that is not easily learned. But this was only the beginning. The production of copper in quantity required the development of a small furnace, which was probably at first a hole in a rock lined with clay, and then there had to come the development of a crucible. Perhaps another five hundred years elasped before the discovery was made that some ores containing mixtures of tin and copper produced what we today call bronze, an alloy of copper that is superior in its hardness, tensile strength, and casting properties. The development of bronze was also probably an accidental discovery since tin ores and copper ores are found in close association in many localities. The processes of annealing and the use of an air blast both for producing high temperatures in furnaces and for the purification of metals had to be discovered. Perhaps the entire development of this technolgy required more time than has elapsed since Julius Caesar landed in Britain. Technologies, unsupported by a body of closely relevant scientific knowledge, do develop, but very slowly.

The development of education up to this point resembles in many ways the development of the early technologies involved in the extracting, smelting, and alloying of metals. We do not refer to present-day teaching practices as they commonly occur in schools as representing a technology, but that is what they are. Many of the important procedures in this primitive technology took hundreds of years to evolve. For example, only

1. Charles Singer, E. J. Holmyard, A. R. Hall, and Trevor I. Williams (eds.), *A History of Technology*, Vol. 5 (Oxford: Clarendon Press, 1958), pp. 76-86.

within the last two hundred years has it become generally accepted in educational literature that rote memorization of large numbers of unrelated details is a very inefficient way to use the learner's time. During the same period the conclusion has also been reached that punishment is an inefficient teaching device and that individual differences in learning rate connot be ascribed solely to differences in moral fortitude. These kinds of discoveries about how to conduct education were probably made many times by individual teachers before they became recognized as prescriptions for educational practice. The formulators of the existing practices of education include such men as Herbart, Pestalozzi, Mann and Montesorri. Many of the practices they advocated have been shown by scientific research to be sound, much as the practices of the early smelters of metal were later shown by chemists to be efficient ways of extracting metal from ores.

We now know that a technology does not have to emerge in this slow fashion, though how the development can be expedited is controversial. One approach is that of borrowing technologies from other areas. A second approach is that of developing a technology uniquely useful to the area based on sound scientific knowledge. There are few clear-cut illustrations of the first of these procedures though all modern industrial processes use ideas borrowed from other industrial areas. Most rapidly developing technologies appear to follow the second path and emerge first through a rapid expansion of scientific knowledge about the phenomena involved, and then through the development of procedures and practices uniquely suited to achieving particular practical goals.

The Application of Existing Technologies to Education

In the field of education some attempt has been made to produce an educational technology through both of these approaches. Let us consider the approach involving the borrowing of an existing technology. This is well illustrated in the education field by computer-assisted instruction that utilizes advanced knowledge in computer science, but conducts education very much as it has long been conducted. Computer-assisted instruction incorporates little new in the way of knowledge of teaching and learning. One of the most ambitious projects in this whole area is that conducted in Palo Alto by Patrick Suppes, who clearly admits that his large and costly computer-controlled teaching arrangement has no foundation in pedagogy or behavioral science.

Suppes presented a paper in 1963 in which he stated that little knowledge exists concerning the development of mathematical concepts in young children in the elementary school. Indeed, he went so far as to say at the end of his paper, "The difficult thing is that I do not yet see clearly what the right sort of language or conceptual framework is."[2] However, Suppes' belief that we do not even have a language in which we can talk about mathematical behavior, let alone any knowledge of mathematical behavior, did not deter him from setting up one of the most expensive systems ever developed in teaching mathematics through a computer-assisted system. The millions of dollars that the United States Office of Education invested in his gadgetry seem to have been invested on the assumption that scientific knowledge about learning is quite unnecessary for the development of a technology of teaching. I cannot understand why

2. Patrick Suppes, "Towards a Behavioral Psychology of Mathematical Thinking," in Jerome S. Bruner (ed.), *Learning About Learning* (Washington, D. C.: Bureau of Research, Office of Education, U.S. Department of Health, Education, and Welfare, 1966), p. 234.

anybody ever thought that this was a good assumption. One can hardly be optimistic about this approach, which seems to be lacking in scientific sophistication, even though it is conceivable that some useful teaching device might evolve from it. I have looked but have failed to find any evidence that this approach has produced advances in teaching, but perhaps it should not be judged in such terms. As a means of conducting research on teaching it may offer some promise, since computer-assisted instruction permits precisely controlled teaching conditions. These judgments are, I think, a fair statement of what is being accomplished in computer-assisted instruction, but many of the statements made about this instructional area by highly influential people savor much more of business ballyhoo. Robert W. Sarnoff, President of the Radio Corporation of America, in a speech dedicating the new RCA Instructional Systems in Palo Alto—described as an electronics technology facility—is quoted as saying that the partnership between the electronics industry and education would make possible "both a rate of learning and a retention far greater than by any other known teaching technique."[3] The speech of Mr. Sarnoff seems to have been influenced much more by what is written in popular magazines than by any scientific findings. I can see no scientific basis for his statement.

The mere carry-over of technologies from other areas in the hope that some of these will apply to education is not likely to be productive; yet it is the approach that has had the greatest federal support in recent years. While it leads to the production of very interesting gadgetry, one would hardly expect it to produce innovation of any great value except through some lucky twist of fate. As far as I can see, luck has not been on the side of those that have supported this kind of enterprise. I can regard the development of the much publicized gadgetry as an interesting engineering feat, but cannot see that it is built on any foundation in the psychology of learning. Such whims can hardly be considered to represent a serious effort to develop a technology in the area of instruction.

The Emergence of Technologies Based on a Science of Behavior

Now let us return to a consideration of the position of those who believe that the development of an advanced technology of education must be based on a science of learning. Sidney Pressey was the first to voice this view, but later B. F. Skinner and his students became its chief exponents. Their fundamental assumption that a technology has to be based on a science of behavior is sound, and although their message has become temporarily lost in a mess of gadgetry, it is a message that ultimately will be widely heeded.

Let us now take stock of what is available in terms of a scientific foundation for the development of an educational technology. A central issue in any discussion of whether we can now develop an advanced technology in the educational field is whether the behavioral sciences, at this time, can provide the necessary foundation for such a development. Skinner in a classic paper on teaching machines commented that when Sidney Pressey announced in 1932 that the "industrial revolution in education" was at hand,[4] Pressey was speaking in advance of his times, for as Skinner went on to point out, the behavioral sciences of the thirties lacked the substance

3. *Behavioral Sciences Newsletter for Research Planning*, 4, 7 (March 31, 1967), 3.

4. Sidney L. Pressey, "A Third and Fourth Contribution Toward the Coming 'Industrial Revolution' in Education," *School and Society*, 36, 934 (November 19, 1932), 668-672.

necessary to support extensive technological development in the education field. However, Skinner believed when he wrote his paper in 1958 that the groundwork of scientific knowledge had been laid. Furthermore, the article went on to imply that the essential scientific knowledge needed for producing an educational revolution was to be found in the results of research on operant conditioning.[5] Although nobody could question Skinner's scientific genius, some did question whether knowledge had reached the point where it could provide the revolution in education that Pressy had envisaged. But lack of knowledge or not, a great impelling force behind Skinner's plan for educational reform soon began to emerge in the form of a large group of devoted and dedicated followers. Some of these who are not so worthy disciples of a very worthy master still provide the essential driving force behind the movement that seeks to establish a new technology.

The development of an educational technology on the basis of the results of research on operant conditioning reflects, to me, undue optimism concerning the extent to which one can successfully generalize from limited research results. Much of the research has involved the development and maintenance of simple motor skills in subhuman organisms, and just how much of the knowledge thus derived is applicable to the understanding of complex human behavior remains a question. Certainly, one would expect that knowledge available concerning operant conditioning would be most applicable in the human sphere to the development of simple motor skills such as, say, typewriting or key-punching. One can also reasonably infer that the available knowledge would be most applicable to understanding and controlling the behavior of young children and mentally retarded children. But those who are utilizing operant conditioning as the basis for the development of an educational technology are not content to limit their applications to the acquisition of simple skills in young children and mental retardates. Indeed, the main thrust of the effort has been in the area of complex verbal learning, where it is least likely to be successful. Efforts to arrange the content of the school curriculum into programs that are presented to the pupil either in the form of a programed text or through a teaching machine represent an attempted application of operant conditioning procedures to problems of symbolic learning. The assumption here is that principles of learning, discovered through the study of simple motor skills, apply also to the acquisition of complex conceptual learning. This assumption goes far beyond any data available at the present time. If it is accepted, it must be through faith rather than any scientific evidence. Though Skinner has written a delightful and witty book in which he speculates on the application of operant conditioning principles to verbal behavior,[6] the book is regarded mainly as fantasy by those considered as experts in the linguistic field.[7]

Certainly some of the principles that the operant conditioning workers stress today seem to be far less important than they were originally thought to be. For example, great stress was placed in the design of early teaching machines on providing immediate reinforcement, but a review of research on immediacy of reinforcement by Renner indicates that it may be

5. B. F. Skinner, "Teaching Machines," *Science*, 128, 3330 (October 24, 1958), 969-977.

6. B. F. Skinner, *Verbal Behavior* (New York: Appleton-Century-Crofts, 1957).

7. See for example, Noam Chomsky, *"Review of Verbal Behavior* by B. F. Skinner," *Language*, 35, 1 (January-March, 1959), 26-58.

a matter of less significance than it was formerly thought to be.[8] Indeed, in much of human cognitive learning immediacy of reinforcement seems to be unimportant, though it retains its position of significance in the learning of some motor skills. In addition, the stress placed in the literature ten years ago on the supposedly immense impact on learning of finding precisely the best order for arranging items in a teaching program has turned out to be a canard.

So much for the general nature of the evidence on which operant conditioning principles are based and the limitations that one would expect to have to apply in the application of these principles. Let us consider what has been the major role of this body of knowledge in the development of a technology of education. As one might well have predicted, operant conditioning procedures have been effective in the development of certain skills by mental retardates and by very young children. The development of toilet skills is probably the most widely cited illustration of this application. There are also some dramatic examples of the application of operant conditioning techniques in the management of the behavior of institutionalized psychotics. This latter success I find a little surprising since the application of the principles involved is very remote from, and different from, the data on which the principles involved were developed. In addition, I find some quite convincing evidence in the work of Lewis and Pask that the application of operant conditioning techniques to the design of trainers for teaching such skills as typing and key-punching does produce teaching situations that are more effective than conventional ones.[9] This research needs to be replicated in different laboratories before I will be fully convinced, but the results are so completely in accordance with expectation that I am inclined to give them considerable credence.

In the area of complex volume, **Teaching Machines and Programed Learning II**, there are almost no data supporting the value of programed instruction in areas involving symbolic learning.[10] Indeed, I think it is fair to say that in most studies where programed instruction has been compared with conventional instruction and where the experiment has been conducted with reasonably good controls, the results tend to show negligible differences between the achievements of the two groups. The use of mechanical devices for the presentation of material at this conceptual level shows a novelty effect, but that is probably all. The pupils using the machines have tended to show rapid learning at first, followed by a rapid decline in acquisition rate. The Glaser volume leaves the impression that the little data there is on the use of programed learning of verbal materials is so disappointing that the promoters prefer not to discuss it. Certainly the startling advances predicted by Skinner a decade previously have not materialized, and the devotees are retreating to the discussion of problems of programing methodology and research techniques. However, they do not appear to be questioning what perhaps needs to be questioned most, and that is whether they are attempting to build on a wrong foundation. Perhaps the principles of operant conditioning that supposedly underlie the entire movement cannot be appropriately tied to problems of programed in-

8. K. Edward Renner, "Delay of Reinforcement: A Historical Review," *Psychological Bulletin*, 61, 5 (1964), 341-361.

9. Brian N. Lewis and Gordon Pask, "The Theory and Practice of Adaptive Teaching Systems," in Robert Glaser (ed.), *Teaching Machines and Programed Learning, II, Data and Directions* (Washington, D.C.: Department of Audiovisual Instruction, National Education Association, 1965).

10. Robert Glaser (ed.), *Teaching Machines and Programed Learning, II, Data and Directions*, (Washington, D.C.: Department of Audiovisual Instruction, National Education Association, 1965).

struction. Let us look around and see what other scientific knowledge might be applied to problems of the development of a technology of education.

The Behavioral Sciences and Educational Technology

The close historical tie that has existed between operant conditioning and attempts to develop teaching machines, responsive environments, and so forth seems to have blinded us to the many others sources of knowledge that could provide a foundation for new developments in educational practice. Indeed, in the eyes of many, educational technology means only the application of principles of operant conditioning, reflecting the fact that so many of those engaged in designing new classroom equipment do bring to the task a background in operant conditioning research and the viewpoint that such research reflects. If this were the only knowledge that we had available, I would say that the new technology would have to be very limited in scope; but there is much more knowledge available that has at least as legitimate a claim to being a basis for educational technology. I cannot summarize here all the present knowledge, but can only point out some of the sources and the general lines of the development of a technology that these sources suggest. Let us begin by considering some of the knowledge about human nature that no technology can possibly afford to ignore.

First, I must point out that man is a primate and shares with other primates certain characteristics. One is his high level of need to interact with other members of his species. Primates are to be contrasted with species that interact with their own members only for sexual purposes, such as the rat or the pigeon. Unlike these, primates spend many hours of the day grooming one another, just as conference registrants stand around in the lobby in little groups picking one another's brains. Man is a highly social species, and not only must this species' characteristic be taken into account in the design of teaching situations, but good capital can be made of it too. I do note, however, that most technological developments and innovations ignore this human characteristic. The socially bleak study carrel, equipped with teaching machines, cathode-ray display tube, tape recorder, and other kinds of gadgetry is well designed for members of a species having very low social needs. This kind of a study carrel is modeled after a pigeon conditioning box. One would expect that children, thus isolated from one another, would not show very sustained behavior. However, if carrels were designed for two children and if tasks were arranged so that closely matched children could compete with each other, then a very efficient instructional situation might result. Under these conditions I would expect highly sustained learning behavior. Students in high school and college do arrange for themselves such socialized learning situations, and pairs of students in study areas represent a very common sight. I would also suspect that the proper matching of the pairs of pupils would be a crucial aspect of the learning situation. In addition, the strong social characteristics of our species suggest to me that a child would much prefer to engage in a discussion of a topic with a teacher than with a machine, even if the machine could discuss with greater competence and fluency than the teacher.

A second characteristic of all complex organisms that I would want to see taken into account is the fact that the adequacy of intellectual development is highly dependent upon the properties of the physical and social en-

vironment in which development takes place. Although most of the present research on matters related to instruction involves the design and use of symbolic materials since these are the easy things to design and redesign, at least as important appear to be problems related to the selection and presentation of actual physical objects and phenomena to which the symbolic world has to be related. The importance of the nature of the physical environment and of the perceptual and motor tasks that the environment presents is clearly demonstrated in such divergent research approaches as those of Hebb and Piaget and their students.[11]

Although some perceptual learning may take place through passive reception, the overwhelming body of evidence indicates that interaction with the environment greatly increases the rate at which such learning occurs. I am impressed with such facts as that kittens held in a movable cradle and moved around a complex perceptual environment undergo much less perceptual learning than the kittens who move around on their own initiative.[12] Harlow, Woodworth, Piaget, and others have long noted the preoccupation of the young creature with the environment and the high level of activity that this preoccupation entails. Neither age nor species appears to be a crucial factor in this phenomenon, for other studies have shown that at least some kinds of perceptual learning on the part of adult humans are highly dependent upon freedom to move around in the environment. The human wheeled around in a chair displays less perceptual learning than the one free to move around of his own accord. Were it not for the fact that all higher organisms show a high rate of activity in relationship to their environment during the growing years, intellectual development would almost certainly not reach the level that it customarily reaches. Another related and tantalizing piece of knowledge in this connection reported from Krech's laboratory is that rats raised in a rich perceptual environment develop greater depth in the cortex of their brains than those brought up under perceptually impoverished conditions.[13] However, some caution must be injected into the speculative interpretation of this kind of evidence since the functional significance of the increase in the size of the cortex is not yet known.

Although symbols can be slowly substituted for concrete situations, readiness for this kind of substitution develops much more slowly than most educated adults believe. This was brought to my attention very forcefully some years ago when Overing and I compared the relative effectiveness of line drawings and a concrete demonstration in teaching sixth- and seventh-grade children the principle of refraction of light. We had expected that the simplicity of the line drawings representing the phenomenon would make them an ideal medium for presenting ideas to the upper elementary grades. On the other hand, the demonstration of the refraction of light through the use of a powerful light beam and a fish tank full of water appeared to be a messy teaching situation since it was cluttered with irrelevant details. What we found was that the realistic situation had advantages, under some circumstances, that the simplified diagram did not have. However the children could use the simplified diagram effectively if they were first given an orientation that related it to

11. See, for example, Joseph McV. Hunt, *Intelligence and Experience* (New York: Ronald Press, 1961).

12. Daniel P. Kimble (ed.) *The Anatomy of Memory*, Vol. I, *Learning, Remembering, and Forgetting* (Palo Alto, Calif.: Science and Behavior Books, 1965), pp. 80-81.

13. Ibid., p. 82.

a realistic setting that they could readily imagine.[14] Although we academicians can live in a world of symbols that have only the remotest connection with the real world, this talent is probably a rare one. Man's biological history has developed him as a species that is naturally highly oriented toward objects and events in the environment, and he retains this aspect of his biological history. He takes to useful symbol substitution with difficulty though he has a large capacity for learning and manipulating words in nonmeaningful ways. The example of millions of orientals turning their prayer wheels and repeating the words marked on them, even though the meaning of the words was lost a thousand years ago, is a caricature of what happens when instruction fails to relate verbally coded information to events in the real world.

In the Overing and Travers experiments on teaching children the principle of refraction, no attempt was made to determine the effect on learning of providing opportunities to manipulate the demonstration. The children were allowed only to observe while listening to a commentary recorded on tape. I would suspect that a greater amount of learning would have been produced if the children had been permitted to perform such acts as changing the angle of the beam of light. I would predict that such activity would improve learning, partly because it would inject more information into the system and partly because children are always highly motivated to manipulate their physical environment and do learn much by doing so. One wonders whether one can ever develop as much fascination for performing operations with symbols or looking at pictures as for performing operations with the real world, except in the case of the very few who become academic scholars. My impression is, and this is purely speculation, that although the human shows a positive and irrepressible tendency to manipulate his physical environment, he typically shows avoidance of that behavior involving the manipulation of symbols called thinking. One can observe this contrast in schools where children undertaking simple experiments are never seen day-dreaming, but children working with books commonly are.

In the design of an educational environment, I can see no substitute for including a wealth of physical and manipulable materials to which symbolic behavior becomes closely tied and intimately related. At no stage in education can this aspect of the educational environment be neglected. For example, I am very confident that a course for teachers in which they conducted experiments demonstrating important facts about learning would provide knowledge with greater transfer value than the usual textbook-oriented course on educational psychology that typically has no impact on the student whatsoever. However, present nonsensical trends in educational research and technology are much more likely to produce a computer-controlled course on educational psychology, with all the useless manipulation of words of the old textbook courses, rather than a course where students witnessed, right before their own eyes, all the major learning phenomena. Note that I am not advocating anything as vague as just looking at children in schools doing the strange things that children do there; I am advocating an experimental laboratory course in learning where the actual control of learning conditions can be directly observed.

14. Robert L. R. Overing and Robert M. W. Travers, "Effects upon Transfer of Variations in Training Conditions," *Journal of Educational Psychology*, 57, 3 (June, 1966), 179-188; and Robert L. R. Overing and Robert M. W. Travers, "Variation in the Amount of Irrelevant Cues in Training and Test Conditions and the Effect upon Transfer," *Journal of Educational Psychology*, 58, 1 (February, 1967), 62-68.

In summary, then, there are two major factors that make it imperative that the pupil be given the opportunity to have a range of experiences involving, on the one hand, direct contact with significant events in the real world and, on the other hand, manipulation of the same information in a verbally coded form. One of these factors is the high preoccupation of the young of all species including our own with the events of the physical world. Hence, pupils are highly energized to engage in learning related to concrete experience. The other factor involves the structure of memory which appears to be organized in such a way that the verbally coded material can be retrieved and used for effective practical application only if it has already been linked with events of the real world. The more direct the linkage, the greater the probability that the application of coded knowledge can be made.

The design of an educational environment which permits a well-planned range of experiences and the laying down of memory traces in such a way that the highly coded and abstract materials learned are well tied to memory traces of direct experience with the real world and related action systems seems to be the most important challenge that the new educational technology should be facing. However, the best-known technologists have shown little concern with this problem since they have been primarily preoccupied with the problem of how to store internally more verbal material in less time. The latter seems to me to be quite a trivial problem. On the other hand, the linking of verbal materials stored in memory with knowledge of the real world impresses me as a problem of central and crucial importance, but not one likely to be solved through the proliferation of gadgetry. Some private publishing and manufacturing concerns are focusing on this problem, and some have engaged in the development of simulated realistic situations for instructional purposes. Although such attempts to develop a technology are to be encouraged, much of the knowledge necessary for their success still has to be evolved in the laboratory.

There is a third major characteristic of our species that the development of a technology should not, but presently does, ignore. This is the fact that the placement of information in the human memory system is very time-consuming. Hence the most careful consideration must be given to the question of what to put in storage. The large curriculum projects have tended to ignore this fact and have generally produced curricula that required more information to be stored in human memory than the earlier curricula.

In addition, memory traces tend to be disrupted when new material is learned; hence these memory traces have to be restored from time to time much as antiques are restored. As more information is stored, more and more time has to be spent in review, and this, in turn, limits the amount of new material that can be taken in. The situation is analogous to that of a man who spends part of the time maintaining his house and part of the time adding to it. As he adds, there is more to maintain, and the time comes when he has no time to make further additions to the house since his entire time must be occupied in maintenance. The memory system is limited in the same way, but fortunately we are not too aware of this limitation since we let much of what we tediously store during school fall into disrepair. Also our daily activity provides a regular review of the information that is most vital to us.

The extraordinary amount of work required to commit information

to memory, and the need for regular review to maintain it there, suggests that great care should be exercised in deciding what is, and what is not, to be learned by heart. The concept of programed learning is generally based upon the assumption that everything taught must be committed to memory. This strikes me as a very good conception of teaching at the subhuman level, but a very poor notion for the design of human teaching situations. One great advantage possessed by the human is that he has ways of retaining information without going through the tedious process of storing it all in his brain. He can also store information outside of himself in books and notebooks and memoranda. In order to obtain access to this externally stored information, he has to store within himself something like an index to that information. A rather brief inventory of organizing ideas in the pupil's brain permits him to gain access to very large amounts of information. The common notion of education, especially that on which the teaching machine technology is founded, seems to be based on the idea that the immediate purpose of education is to turn the child into a person with a neuro-encyclopedia in his head. I would prefer to see him become, as Broadbent suggests, an index to the encyclopedia.[15] For example, one of the tedious learnings that occurs in elementary school is how to extract a square root. Although pupils may work on this problem for a week, they will almost certainly have forgotten how to extract a square root by the time they reach adulthood. If they ever have to calculate one as an adult, they will have to relearn the entire procedure. They would have saved themselves considerable time in the first place if they had learned only that there are routines for calculating square roots and that they are available in books. Much of the detail given, for example, in biology books would also fall into this same category of information that should not be store internally. However, in order to develop this concept of instruction three major changes would have to be made. First, books would have to be differently designed, and reference works would have to be made generally available to pupils in schools and to those who have already graduated. Second, examinations would have to be of the open-book type, in which the pupil shows his proficiency in deriving information from reference works. Third, work in schools would have to be very different from the workbook-oriented activity that is seen in many current so-called innovation projects.

What I am trying to stress here is a belief that an educational technology that merely attempts to speed up the kind of learning that has typically taken place in schools is not likely to be effective. What appears to be needed is a technology that will help man to use available knowledge with great efficiency while storing little of it inside himself. Many of us suspect that the goal of educational technology of speeding up learning may be a fruitless quest, for the ceiling on the rate at which information can be placed in permanent storage may already have been reached. Research literature certainly provides no convincing data that a variation in the conditions of learning in classrooms in modern schools produces a variation in the rate at which information is stored. Therefore I am inclined to conclude that the typical goal of the current educational technology-namely, that of speeding up the internal storage of knowledge-is a profitless one. Other goals have to be adopted.

I have mentioned just three characteristics of the human organism that I would want to take into account in the design of educational en-

15. D. E. Broadbent, "The Well Ordered Mind," *American Educational Research Journal*, 3, 4 (November, 1966), 281-295.

vironments and that, I believe, the development of any effective technology cannot ignore, but there are others. I would not, of course, neglect all of the ideas that the operant conditioning enthusiasts put forward, but I would want to be very selective in what was applied. The application of the concept that knowledge of results is necessary for certain kinds of learning has had a long history in education, and I would not want to discard such a valuable concept; but I would object to the lumping together of knowledge of results and the dispensing of M and M candies into a single, broad category entitled "reinforcement." Indeed, those aspects of operant conditioning that I would retain as the basis for an educational technology would be those that have had a history of significance in education. For example, the emphasis that the operant conditioning school places on the sequencing of subject matter is highly reminiscent of the Middle Ages. We are probably no nearer today than were the schoolmen of the Middle Ages to finding appropriate subject matter sequences within the disciplines, but we do at least continue to recognize that there may be a problem. Nobody knows to what extent sequencing is a significant problem in subject fields other than mathematics where the problem has been largely solved. In most areas knowledge simply does not fit into a single linear arrangement but can be presented in a very large number of different ways. The different arrangements of historical subject matter would appear to be almost limitless, and there is no practical way of testing the teaching value of even a small fraction of these alternatives. Sequencing will have to be done in terms of a set of principles of sequencing that have not yet been developed. Those who talk most about the importance of sequencing subject matter have done little to solve the enormous difficulties that the practical application of this concept involves.

IN CONCLUSION

The thesis of this paper has been that the development of a technology of education will not emerge merely from the attempt to adapt technologies developed for other purposes; yet most of the efforts that have been granted financial support have been of this nature. On the contrary, what appears to be needed for the development of a sound technology of education is a firm foundation of scientific knowledge in the area of learning. Most of those concerned with the development of an educational technology have done little to search the literature of psychology for information that could be used as a sound basis for their work, though the Research and Development Center at the University of Pittsburgh has initiated such a project. Indeed, the tendency has been to seize, with almost fanatical zeal, a few psychological concepts that happen to be popular at the time and to disregard the remaining body of psychological knowledge. The thesis of this paper is that there are psychological concepts of perhaps greater significance to the design of a technology than those that are commonly found in writings on operant conditioning. Although there are tremendous difficulties involved in deciding what concepts derived from research on human and animal learning have application to the design of a classroom technology, a broad search will yield far more significant concepts than are ordinarily recognized by educational technologists.

A second major point I have made is that the development of a new technology of education has been tied, unfortunately, to the achievement of very traditional goals. The typical objective of computer assisted in-

struction is to do what teachers have long been attempting to do, only to do it more rapidly. The objective is still that of stuffing little minds with information, but at a faster rate. This partnership of the old and the new presents a picture somewhat similar to that of an eighteenth-century buggy equipped with a large modern gasoline engine that drives it along at ten miles per hour. The thesis was presented that much more could be achieved by coupling attempts to develop a new technology with new goals that the new technology might make possible. More could probably be accomplished by conducting research and development related to the educational goal of making man a more efficient retriever and user of available knowledge than that of making man the primary storage system of information. Retrieval system theory and the advanced development of computers as searching devices appear to make possible the development of a new concept of education in this respect. At present we know almost nothing about the problem of educating man as an information retrieval system, largely because, since the days of antiquity, the brain of man has been regarded as a primary means of storing knowledge rather than as a part of a knowledge retrieval system through which man can obtain access to the entire available system of coded knowledge. The computer and modern technology related to information handling can become in the educational setting the key to releasing man from the limitations placed upon him by the fact that committing material to memory is a desperately time-consuming task. The problem is to provide man with the greatest access to knowledge while requiring him to memorize the minimum amount of material.

Many problems stand in the way of the rational development of a technology of education. One is the fact that much of the work now in progress is being undertaken outside of colleges of education by persons who have had little contact with pedagogy. The blame for this lamentable lack of coordination between persons in education and behavioral scientists must be attributed largely to the unfavorable atmosphere for research that still exists within the typical college of education. Research-oriented institutions for training school personnel, such as Teachers College, Chicago, Stanford, and Peabody, are so rare that they stand out as shining exceptions. There are still, for example, many well-established, large, old universities that train school personnel by the legion but sponsor virtually no ongoing research. It is hardly surprising that enthusiasts for education reform on the outside have seized the initiative for technological developments, but the unfortunate result has been that these have typically demonstrated sophistication in the design of gadgetry but naivete in educational thought. More initiative must be taken in this respect by the graduate schools of education if the situation is to be remedied. Unless this initiative is taken, we will find outselves watching twentieth-century electronics driving nineteenth-century school programs.

A final comment must be made to the effect that the development of a technology is also severely handicapped by political opportunism at the national, local, and personal level. Massive spending on hot-shot projects —or what Washington calls high-priority projects—is not likely to achieve even the political advantage anticipated. The team of the scientist and educator must be free to work in a rather different atmosphere than exists at present if Sidney Pressey's dream of an industrial revolution in education is to be realized.

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Newsletter Editor
Dr. Francis E. Clark
Dept. of Industrial Education
Texas A and M University
College Station, TX 77843
(713) 845-3016